Self-assembled Multiferroic Nanostructures

H. Zheng, J. Wang, S. E. Lofland, Z. Ma, L. Mohaddes-Ardabili, T. Zhao, L. Salamanca-Riba, S. R. Shinde, S. B. Ogale, F. Bai, D. Viehland, Y. Jia, D. G. Schlom, M. Wuttig and R. Ramesh

We report a novel approach to form self-assembled complex oxide nanostructures. The approach consists of spontaneous phase separation of a spinel-perovskite solution, assisted by heteroepitaxy on a single crystal substrate. We illustrate this approach with ferroelectromagnetic BaTiO3-CoFe2O4 nanostructures, deposited on single-crystal SrTiO3 (001) substrates by pulsed laser deposition (PLD) from a single Ba-Ti-Co-Fe-Oxide target. The films are epitaxial in-plane, as well as out-of-plane with self-assembled hexagonal arrays of CoFe2O4 nano-pillars embedded in a BaTiO3 matrix. The CoFe2O4 nano-pillars have uniform size and average spacing of 20-30 nm. The nano composite is simultaneously ferroelectric/piezoelectric (corresponding to the BaTiO3 matrix) and ferromagnetic (corresponding to the CoFe2O4 nano-pillars). The temperature dependent magnetic measurements illustrate a coupling between the two order parameters of polarization and magnetization, by a change in magnetization at the ferroelectric Curie temperature. We believe that this approach to the formation of self-assembled nanostructures is generic and manifests itself in other such spinel-perovskite systems, thus making it of great interest and value to a broad materials community.

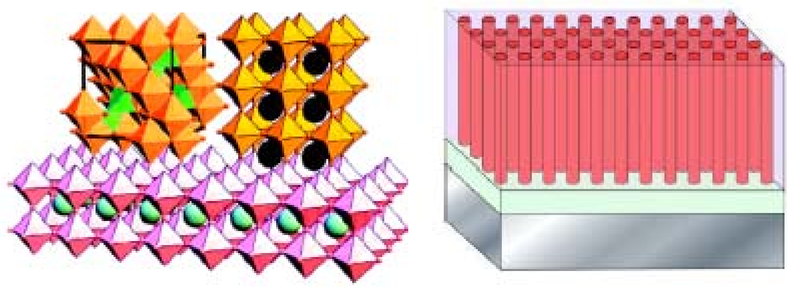

Figure 1:
(A) Epitaxial alignment of spinel and perovskite on perovskite substrate;
(B) Schematic illustration of a self-assembled nanostructures thin film formed on the substrate.

Polarization Reversal and Memory in a Multiferroic Material Induced by Magnetic Fields

N. Hur, S. Park, P. A. Sharma, J. S. Ahn, S. Guha, and S-W. Cheong

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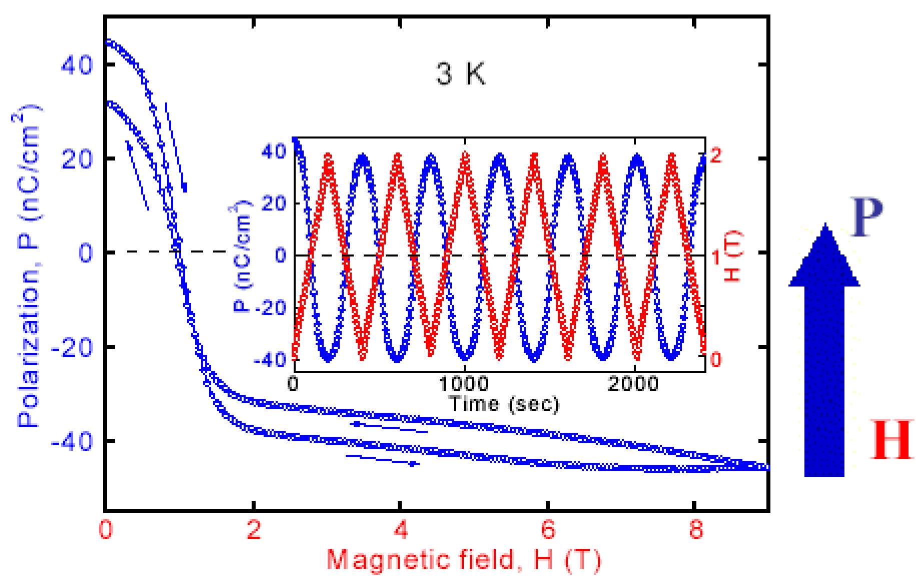
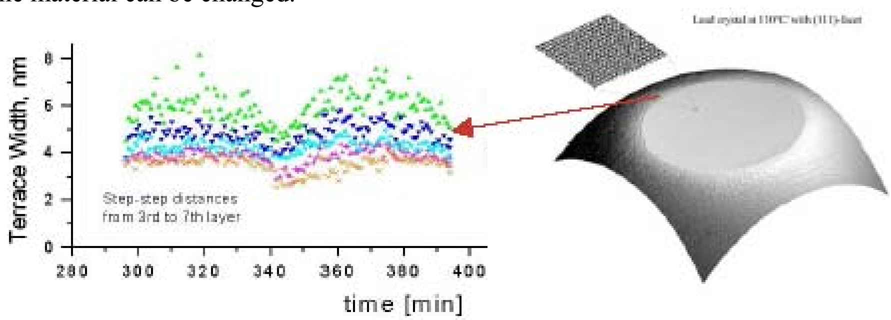
Ferroelectric and magnetic materials have been a time-honored subject of study and have lead to some of the most important technological advances to date. Magnetism and ferroelectricity are involved with local spins and off-center structural distortions, respectively. These two seemingly unrelated phenomena can actually coexist in certain unusual materials, termed **multiferroics**. The understanding of this remarkable occurrence remains a scientific challenge. Despite the possible coexistence of ferroelectricity and magnetism, any profound interplay between them has been rarely observed. This fact has largely prevented the realization of devices with a previously unavailable functionality, which these multiferroics could make possible. We have recently discovered an astonishing interplay between ferroelectricity and magnetism in the **multiferroic $TbMn_2O_5$**, demonstrated by **a highly-reproducible electric polarization reversal** and **permanent polarization imprint** that are both **actuated by applied magnetic fields**. Our results point to **new multi-functional device concepts** such as **magnetically-recorded ferroelectric memory**.

Polarization reversal by magnetic field



Fluctuations at the Nanoscale: Good, Bad or Interesting?

Atoms are always moving: they vibrate, squeeze their neighbors, or even move around to different positions altogether. In the normal materials we deal with every day, this atomic motion doesn't matter. There are so many atoms that all the randomness just averages out. In nanoscale materials, the issues are quite different because there aren't so many atoms. Now when a few atoms move about, the properties of the material can be changed.



Example of structural fluctuations in the nanoscale features of a crystalline object (a micron-scale Pb crystallite) as it approaches its equilibrium shape. The terraces bounding the edge of the crystallite fluctuate with increasing amplitude until just before the nucleation of a new shrinking layer occurs (as at ~340 min.)

Figures courtesy of K. Thürmer, University of Maryland NSF-MRSEC.

Researchers at the University of Maryand – NSF MRSEC have demonstrated that these atomic fluctuations can be measured directly, and equally importantly that there are predictable patterns to the randomness. They have used a new theoretical approach called "First Passage" to analyze the observations and demonstrated that the atomic fluctuations follow a well-defined probability law.

The exciting implications of this research will occur in a broad range of potential applications for nanoscale materials, including information storage, noise, electrical transport and switching, self assembly into patterned structures, chemical reactivity and sensing. In each of these applications, fluctuation phenomena can generate nanoscale behaviors that are NOT simply scaled down versions of the macroscopic analogs. Using theories of "stochastic predictability" to harness these behaviors is one of the great challenges in the near future of nanoscience.